ASCAT scatterometer ocean calibration

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***Abstract*—The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) is responsible for the absolute calibration of the new Advanced scatterometer (ASCAT), onboard MetOp-A, which mainly relies on the use of transponders. An alternative calibration method, which uses scatterometer measurements over the ocean, is presented here. The method is based on the knowledge of the backscatter signal modulation by the ocean surface, which is derived from previous C-band scatterometer missions, and on the use of numerical weather prediction wind output as calibration reference. The method proves to be very useful in providing guidance to EUMETSAT calibration efforts and provides continuity of the C-band scatterometers. Moreover, the ocean calibration results in very good quality winds. As such, within the framework of the EUMETSAT Ocean & Sea Ice Satellite Application Facility, the Royal Netherlands Meteorological Institute has released a demonstration ASCAT 25-km wind product, which is available at http://www.knmi.nl/scatterometer since 28 March 2007.**

Keywords: scatterometer, ocean calibration, geophysical model function, measurement space visualization.

I. INTRODUCTION

A new scatterometer, the so-called Advanced scatterometer (ASCAT), onboard MetOp-A satellite was successfully launched on October 19 2006. During the commissioning phase period (for ASCAT extended until the end of June 2007), one of the main goals is to accurately calibrate the instrument.

The absolute calibration of the backscatter signal of a scatterometer is essential for the retrieval of optimum quality geophysical products. For the calibration of the European Remote-sensing Satellite (ERS) scatterometers the European Space Agency (ESA) performed the absolute calibration by a controlled radar return to the scatterometer from transponders when these are illuminated by one of the three scatterometer radar beams. In addition, an inter-beam comparison was planned over the rain forest where the radar cross section is known to be very stable and rather time independent. Furthermore, the incidence angle response is known to be smooth over the rain forest. At first, the two techniques resulted in an inconsistent calibration. It was at this point that an ERS ocean calibration method proved very useful. It helped to detect an interpretation problem of the results obtained with the transponders. After solving the initial problems, the three calibration methods are giving results that lie within the ESA specifications for the radiometric accuracy of the ERS scatterometers, which is 0.2 dB.

The ERS ocean calibration method consists of comparing the average measured backscatter from the antennae to the simulated backscatter from collocated Numerical Weather Prediction (NWP) winds over a uniform wind direction distribution, to assess the absolute values of the measurements and to show inter-beam biases [1]. To simulate the backscatter, a forward model or Geophysical Model Function (GMF), i.e., a function that relates sea surface wind vector to backscatter, is needed.

Due to an unexpected delay in the set-up of the ASCAT transponders, ocean calibration plays a central role in the calibration of ASCAT during commissioning. The main uncertainty in the ASCAT calibration lies in the gain pattern across the swath of all six antenna beams. Since the receiving system is expected to be linear over the backscatter dynamic range, scaling of backscatter values as a function of beam and across-swath position is expected to improve the calibration.

Since both ERS scatterometer and ASCAT are C-band vertically-polarized fan antennae beam systems, an ERS GMF, such as CMOD5 [2], can be used for ASCAT calibration. Moreover, this constrains consistency between the ERS and ASCAT C-band mission, which is useful for climate applications.

An important tool for ASCAT inter-beam calibration is the visualization of triplets of radar backscatter, i.e., every Wind Vector Cell (WVC) is illuminated by three antenna beams at different azimuth angles, which measurements may be visualized in a 3-dimensional measurement space [1]. For a given WVC number, i.e., position across the swath, it is shown that the ERS measured triplets are distributed around a well-defined “conical” surface and hence that the signal largely depends on just two geophysical parameters, i.e., wind speed and direction. Such cone (visualization of, for example, CMOD5 GMF in the measurement space) can in turn be used for ASCAT calibration. That is, for coincident ERS/ASCAT incidence angle ranges, the ASCAT triplets are also expected to be distributed around the cone in the same way as for the ERS scatterometer (see Fig. 1). Inconsistencies between the cloud of triplets and the cone in any direction of the 3D space are mainly due to absolute beam biases, which should be adequately removed (calibration).

As such, the visualization tool provides guidance on how to correct for beam biases and an NWP wind reference is used to provide an absolute reference for calibration across all incidence angles. This ASCAT ocean calibration, which is

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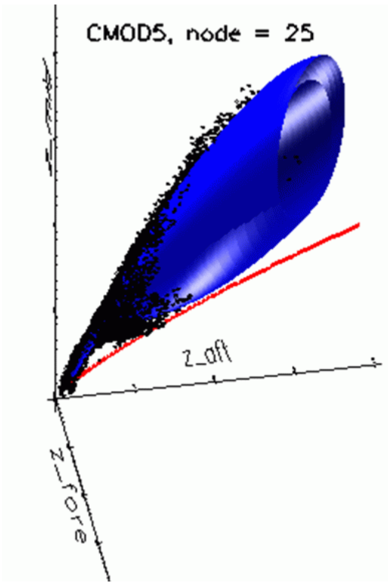


Figure 1. Visualization of the CMOD5 GMF (blue surface) and the ASCAT triplets (black dots) in 3-D measurement space, for WVC number 25.

performed in the context of the Ocean & Sea Ice (OSI) Satellite Application Facility (SAF) project of EUMETSAT, consists of different steps, which are summarized in this paper. More detailed information can be found in [3].

II. VISUAL CORRECTION

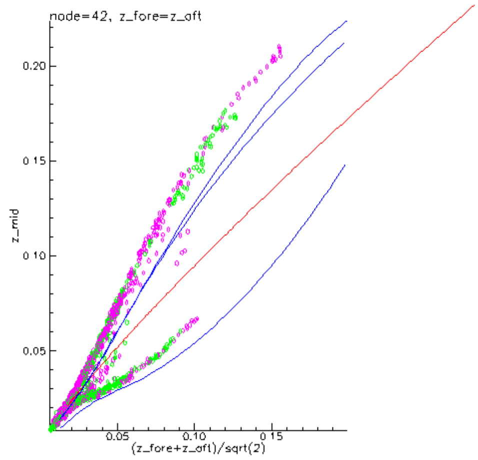
As mentioned above, visualization in the 3D measurement space can be very helpful for ASCAT inter-beam calibration. In particular, systematic displacements between the ASCAT measurements (triplets) and the CMOD5 cone can be easily detected and corrected through this visualization.

A first correction is therefore done in order to match the cloud of ASCAT backscatter (σ°) triplets (corresponding to the fore, mid, and aft beams) to the CMOD5 GMF in the 3-D measurement space. Fig. 1 shows an example of such visualization, where the axes are in z-space, i.e., (z_{fore}, z_{aft}, z_{mid}) where $z=(\sigma°)^{0.625}$ [4]. The double folded cone surface of CMOD5 is depicted in blue. The measured data are shown as a cloud of black points around the cone surface.

Fig. 2a shows a cut of the wind cone at $z_{fore} = z_{aft}$ and the projection of the triplets in the vicinity of such plane, for WVC 42, i.e., the outermost WVC of the right swath. The measurement triplets correspond to the EUMETSAT first release of the ASCAT level 1b data. Green and purple points belong to the inner (downwind) and outer (upwind) sheets of the cone surface, respectively (see Fig. 1). A correction (scaling) factor for the mid beam (vertical axis) is determined such that the triplets fit the CMOD5 cone for each WVC. Fig. 2b shows the distribution of triplets after correction.

Fig. 3a shows the projection of the wind cone and the triplets on the plane $z_{mid} = 0$. Correction factors for the fore and aft beams can be determined, such that the measurement points are distributed symmetrically with respect to the diagonal. The

a)



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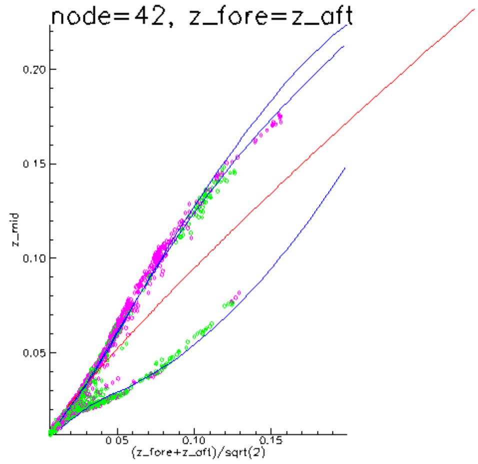


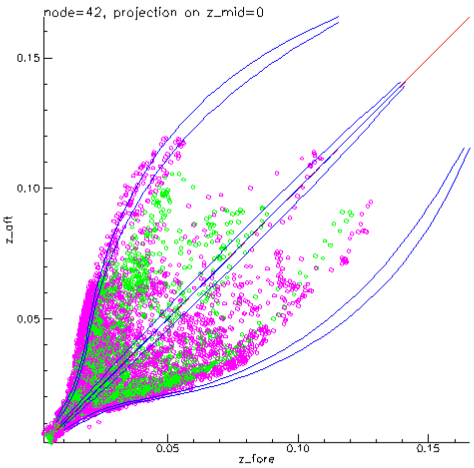
Figure 2. Cut of the CMOD5 cone (blue curves) at the vertical plane $z_{fore} = z_{aft}$ for WVC number 42, and projection of the triplets (coloured dots) in the vicinity of such plane before (top) and after (bottom) visual correction.

scaling correction factors (s^{cone}) are coupled in the following way:

$$s_{fore}^{cone} = 1 / s_{aft}^{cone} \tag{1}$$

III. WIND SPEED BIAS CORRECTION

After balancing the fore and aft beam for cone symmetry and bringing the mid beam measurements in line with the CMOD5 values on the cone, most systematic deviations perpendicular to the cone disappeared. One degree of freedom remains in the normalisation of the cone and lies in the translation of the cone along its major axis, which mainly depends on wind speed. Its first order effect is a wind speed bias after CMOD5 inversion. Therefore, a second correction is a)



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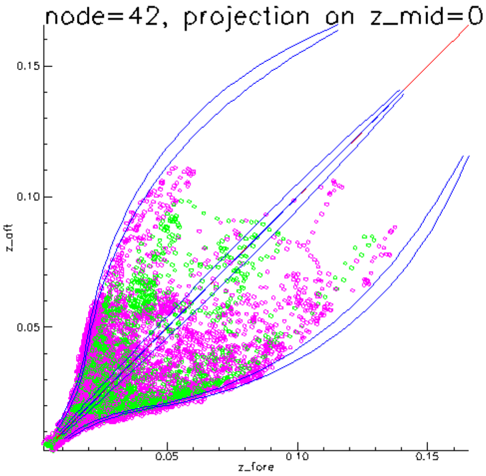

Figure 3. Projection of the CMOD5 cone (blue curves) and the triplets (coloured dots) on the plane $z_{mid} = 0$ for WVC number 42, before (top) and after (bottom) visual correction.

applied on top of the visual correction to achieve a uniform wind speed bias.

To perform the wind speed bias correction, we take the European Centre for Medium-Range Weather Forecast (ECMWF) model 10-m wind as reference to compute the scatterometer retrieved wind speed bias (at each WVC). ECMWF speeds are recently close to unbiased [5]. Given the fact that CMOD5 depends quasi-linearly on wind speed [2] and that 8 m/s is the mean global speed, the CMOD5 wind speed sensitivity at 8 m/s is taken to represent the full wind domain sensitivity. As such, the corrections to the backscatter measurements in z-space are formulated as follows:

$$s^{wind} = \Delta v \cdot \frac{1}{\bar{z}} \cdot \frac{dz}{dv}; \qquad (2)$$

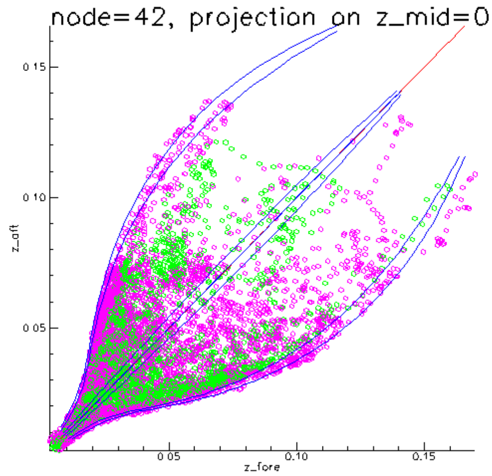

Figure 4. Same as Fig. 3b but for visual + wind speed bias corrected triplets.

where s^{wind} is the backscatter correction factor (scaling); Δv is the speed bias; $\bar{z}$ and dz/dv are the mean backscatter value and the mean CMOD5 sensitivity, respectively, at 8 m/s.

The visualisation tool can now be used to check for consistency of the wind speed bias corrected triplets with the CMOD5 cone. Fig. 4 shows the same as Fig. 3b but with the wind speed bias correction added. Note that the triplets in Fig. 4 are stretched away from the origin towards higher CMOD5 wind speed values, as compared to Fig. 3b, but remain consistent with the CMOD5 cone. The same conclusions are derived by looking at the vertical plane ($z_{fore} = z_{aft}$) plot and other WVCs (not shown).

IV. OCEAN CALIBRATION ASSESSMENT

To assess the absolute calibration values, the ERS ocean calibration tool is used. As mentioned in section I, the ocean tool compares the average measured backscatter from an antenna to the simulated backscatter from collocated Numerical Weather Prediction (NWP) winds [1]. As in section III, ECMWF winds are used as reference. More details on the method can be found in [6].

Fig. 5 shows the difference between the real and the ECMWF simulated (using CMOD5 GMF) measurements as a function of incidence angle, for the six ASCAT antenna beams. The calibration values for the latest (calibration) release of EUMETSAT level 1b data (top) and the KNMI calibrated (i.e., visual + wind speed bias corrected) data (bottom) are shown. It is clear that the latter shows smaller values than the former, which is an indication of improved calibration. Moreover, the range of differences in Fig. 5b is similar to the one obtained for the calibrated ERS data [6].

V. WIND VALIDATION

To further validate the KNMI calibration (visual + wind speed bias corrections), the quality of the retrieved winds is checked against ECMWF winds. The KNMI calibrated a)

b)

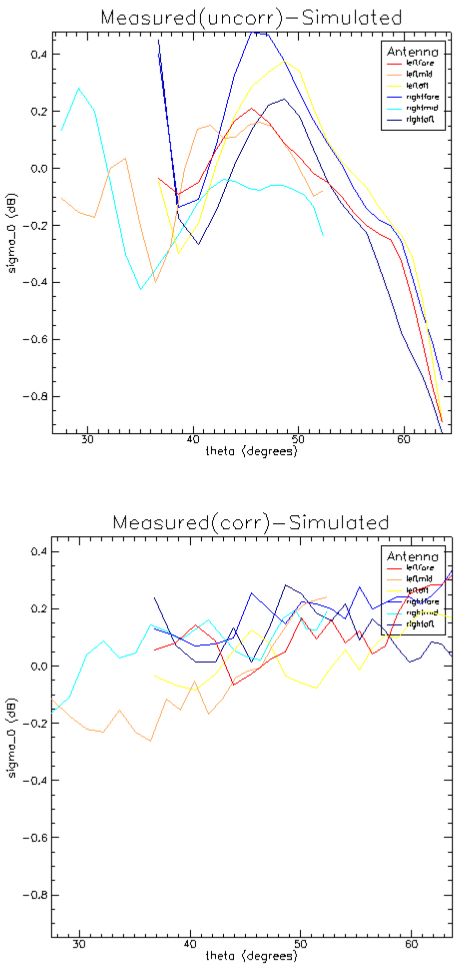

Figure 5. Difference between the real (ASCAT) measurements and the ECMWF simulated measurements (using CMOD5 GMF) as a function of incidence angle, for the six ASCAT antenna beams, before (top) and after (bottom) visual + wind speed bias corrections.

backscatter measurements produce unbiased winds (as expected from the wind speed bias correction in section III) and low root mean squared (RMS) values: 1.4 m/s in wind speed and 16.6° in wind direction. The latest release of EUMETSAT level 1b data results in biased winds (up to 1 m/s in the outermost WVCs) and higher RMS (lower quality) in the wind direction domain (17.2°).

The ASCAT wind product accuracy requirements are 2 m/s in wind speed and 20° in wind direction. Although the RMS scores do not provide a measure of the ASCAT wind accuracy but rather the level of agreement with ECMWF winds, it is clear that this agreement is a good indication of the product high quality.

VI. Conclusions

The KNMI ocean calibration proves to be a very effective procedure. Only with a few orbits of ASCAT data, the corrected backscatter measurements produce good calibration results and winds of high quality. After an operational readiness review, KNMI, the centre responsible for the ASCAT level 2 (wind) processing, was authorized to disseminate ASCAT-derived winds in "demonstration" mode.

The ocean calibration tool used in this paper can handle both real and simulated data. Simulations are useful to assess the accuracy of the method. A simulation run with realistic "true" wind distribution and realistic measurement and NWP wind-component error values is performed. The results show that the impact of the NWP wind component errors on the calibration is large compared to that of the measurement errors (not shown). Some absolute ocean calibration differences between real and simulated data still need to be further investigated, but relative beam calibration can be done with confidence.

Since the commissioning phase started, KNMI has provided feedback to EUMETSAT on the backscatter calibration. EUMETSAT has released so far three different level 1b versions. Although the latest release is the closest to the KNMI calibration, some differences still remain, especially at the outermost WVCs of the swath. Such WVCs are outside the incidence angle range for which CMOD5 was validated. Since the ocean calibration relies on CMOD5 cone, an independent calibration is needed at the mentioned WVCs. A similar exercise to the one presented here but using sea ice data and the ERS-derived ice model [7] can be carried out for such purpose. Although the ice model has not been validated at high incidence angles, it behaves quasi-linearly and, as such, extrapolation to the new incidence angle range is more reliable than for CMOD5. First results at IFREMER are promising.

Further ice calibration will be carried out in the near future and, together with the ocean and rain forest calibration, it will be used to improve the interpretation of the transponder calibration, the last step before EUMETSAT provides fully calibrated level 1b data.

Acknowledgment

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